

The Global Precipitation Measurement (GPM) Microwave Imager (GMI) Instrument: Role, Performance, and Status

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Abstract—The Global Precipitation Measurement (GPM) Microwave Imager (GMI) instrument is a multi-channel, conical-scanning, microwave radiometer serving an essential role in the near-global-coverage and frequent-revisit-time requirements of GPM. As a part of its contribution to GPM, NASA will provide a GMI instrument and a spacecraft for the Core observatory and is considering the acquisition of a second GMI instrument for placement aboard a constellation spacecraft with a payload and orbit to be defined. In March 2005, NASA chose Ball Aerospace & Technology Corporation to provide the GMI instrument(s). This paper describes the GMI instrument, the technical performance requirements, its role within the combined passive and active microwave measurements on the Core observatory, and the timeline for GMI development and acquisition.

I. INTRODUCTION

The Global Precipitation Measurement (GPM) mission will initiate a new era in precipitation measurement in terms of its global extent and frequency of sampling [1]. Plans call for a GPM constellation consisting of eight spacecraft, with each spacecraft carrying a conical-scanning, microwave radiometer among its instrument complement. One member of the constellation, designated the ‘Core’ observatory, is at the heart of GPM with assets and instrumentation contributed by the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA). The Core observatory is uniquely instrumented with two cross-track scanning radars, the Dual-frequency Precipitation Radars (DPR) [2], and a conical-scanning radiometer, the GPM Microwave Imager (GMI). This instrumentation enables the Core spacecraft to serve as both a ‘precipitation standard’ and as a ‘radiometric standard’ for the other GPM constellation members. The GMI is characterized by nine microwave channels ranging in frequency from 10.65 GHz to 89.0 GHz. The channels are similar to those on the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) [3]. With a 1.2 m diameter antenna, the GMI will provide significantly improved spatial resolution over TMI.

NASA is acquiring the GMI instrument(s) through a commercial procurement. The contract for GMI was awarded in March 2005 to the Ball Aerospace & Technology Corporation of Boulder, CO. A second GMI, an identical copy of the first, may be flown aboard a GPM constellation member spacecraft. The second GMI is available as a contract

option. Delivery of the first GMI unit will occur September 2009. Launch of the Core observatory is planned for December 2010.

II. SCAN GEOMETRY

The conical-scanning geometry of the GMI is illustrated in Fig. 1. The off-nadir-angle defining the cone swept out by the GMI is set at 48.5 degrees which represents an earth-incidence-angle of 52.8 degrees. To maintain similar geometry with the predecessor TMI instrument, the earth-incidence angle of GMI was chosen identical to that of the TMI. Rotating at 32 rotations per minute, the GMI will gather microwave radiometric brightness measurements over a 140 degree sector centered about the spacecraft ground track vector. The remaining angular sector is used for performing calibration; i.e. observation of cold space as well as observation of a hot calibration target.

The 140 degree GMI swath represents an arc of 1170 km on the Earth surface. For comparison, the DPR instrument is characterized by cross-track swath widths of 245 km and 120 km, for the Ku and Ka-band radars respectively. Only the central portions of the GMI swath will overlap the radar

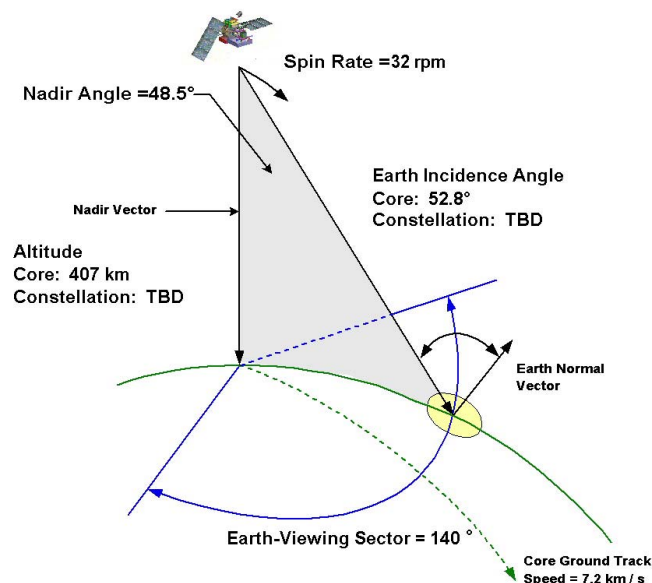


Figure 1. GMI scan geometry.

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swaths (and with approximately 67 second duration between measurements due to the geometry and spacecraft motion). As will be described later, these measurements within the overlapped swaths are important for improving precipitation retrievals, and in particular, the radiometer-based retrievals.

III. TECHNICAL PERFORMANCE AND RESOURCE ALLOCATION

The GMI is equipped with nine microwave channels with characteristics described in Table 1. The center frequencies and bandwidths are similar to those of TMI with minor changes to reflect compatibility with protected allocations for passive remote sensing and all GMI channels lie within protected bands. Noise equivalent delta temperature (NEDT) values are valid for the corresponding integration times where the integration times represent scan movement through one antenna beam width. Note that these are not the GMI operational integration times; a discussion of proposed operational sample times is provided later in this paper.

GMI beam efficiencies for all channels will exceed 90% where beam efficiency is defined as the percentage of energy collected from an isotropic scene within the solid angle defined by 2.5 times the channel half-power beam widths and approximating the antenna main lobe between first nulls.

Table 2 provides the primary resource allocations available to the GMI. The power allocation of 90 W, drawn from the spacecraft 28 v DC supply, is an orbital average allocation. The data rate of 25 kbps is further allocated as 24 kbps for scientific data and 1 kbps for instrument housekeeping data.

Table 1. GMI REQUIRED TECHNICAL PERFORMANCE.

Channel	Ctr. Freq. (GHz)	Ctr. Freq. Stab. (\pm MHz) [a]	Band-Width (MHz) [a]	Pol.	Int. Time (ms)	NEDT (K) [a]	Beam Width (deg.) [a,b]
1	10.65	10	100	v	9.7	0.60	1.75
2	10.65	10	100	h	9.7	0.60	1.75
3	18.70	20	200	v	5.3	0.70	1.00
4	18.70	20	200	h	5.3	0.70	1.00
5	23.80	20	200	v	5.0	0.90	0.90
6	36.50	50	1000	v	5.0	0.40	0.90
7	36.50	50	1000	h	5.0	0.40	0.90
8	89.00	200	6000	v	2.2	0.70	0.40
9	89.00	200	6000	h	2.2	0.70	0.40

[a] Maximum permissible values.

[b] Antenna beam widths are 3 dB values.

Table 2. GMI RESOURCE ALLOCATIONS

Resource	GMI Allocation
Mass	100 kg
Power	90 W
Data Rate	25 kbps

IV. GMI ACQUISITION AND TIMELINE

NASA awarded the contract for the GMI to Ball Aerospace & Technologies Corporation in March 2005. The acquisition is through a cost-plus-fee type contract. The government solicitation requested two options to the contract: (1) provision for a second GMI instrument of identical build to the first, and (2) provision of four high frequency channels about 166 GHz and 183.31 GHz. The government maintains the ability to exercise the option for a second GMI instrument until the milestone of instrument preliminary design review. The high frequency channel option was declined at contract award.

The contract calls for delivery of the first GMI instrument in September 2009, 54 months following award. The government will acquire the Core spacecraft commercially in a competitive process through the NASA Rapid Spacecraft Development Office. Ball will deliver the GMI to the Core spacecraft vendor where it will be integrated aboard the spacecraft and where the observatory will undergo environmental testing. The launch of the GPM Core observatory is planned for December 2010 aboard a JAXA-provided H-IIA launch vehicle from Tanegashima, Japan.

NASA is seeking partnership opportunities, internationally and domestically, for a Constellation spacecraft which would accommodate a second GMI instrument if that option is exercised.

V. GMI CONCEPT AND DESIGN

The Ball Aerospace concept for the GMI is illustrated in Fig. 2. The GMI employs an offset parabolic antenna with an aperture size of 1.2 m. The antenna subsystem includes four feedhorns serving the nine channels. Each frequency is allocated an independent feedhorn with the exception of a shared feedhorn for the 18.7 GHz and 23.8 GHz channels.

The antenna subsystem and receiver electronics rotate at 32 rotations per minute. A stationary thermal shroud, with an opening to cold space, surrounds the rotating instrument subsystems. The instrument will be responsible for its own momentum compensation. The control circuitry and logic governing instrument spinning and momentum compensation is contained within the instrument controller assembly. The instrument controller assembly and momentum wheel, providing momentum compensation, are mounted beneath the shelf supporting the GMI sensor.

Of particular interest are design features enabling superior instrument calibration. These design features include: (1) a four-point calibration technique employing an internal noise

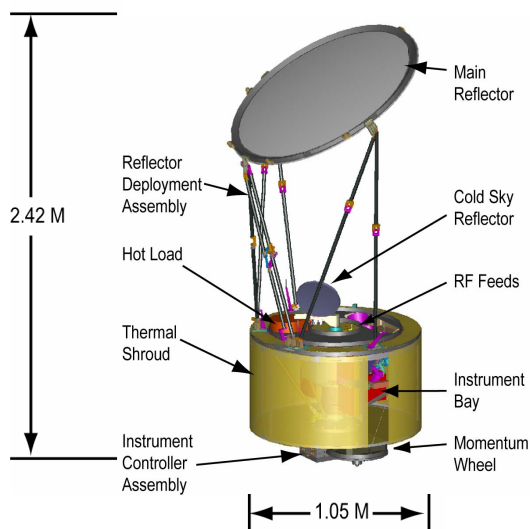


Figure 2. Ball Aerospace GMI concept.

diode on each channel in conjunction with the standard cold sky and hot load calibration targets, (2) a low emissivity annular ring on the instrument deck for thermally isolating the hot load, and (3) a well-monitored hot calibration load with 14 platinum resistance thermometers placed within the target.

The four-point technique provides a polynomial fit to the instrument response which typically, in other space-borne radiometers, is estimated by a linear fit. The conventional hot and cold targets are measured as per the typical total power calibration scenario. However, in addition, a noise diode is switched on momentarily during the hot load and cold sky target views providing two additional temperature points available for calibration. The benefit of the technique is a more accurate instrument calibration. Details on the four-point technique can be found in the paper by McKague in these proceedings [4].

The annular ring on the instrument deck will be constructed of a metallic-coated material of low heat capacity and characterized by low emissivity at infrared and microwave wavelengths. The ring serves to radiatively isolate the hot load target from the instrument deck while the instrument deck rotates beneath it. In addition, the hot load and annular ring have enveloping shrouds to prevent solar heating either directly or through reflection. This design will help minimize temperature gradients within the hot load.

All channels of the GMI will be calibrated to an accuracy of 1.35 K or better where this calibration value applies to the GMI main lobe temperature.

VI. SPATIAL RESOLUTION AND SAMPLING

Fig. 3 illustrates the instantaneous field of views (IFOVs) of the GMI channels and their translation from one scan to the next. The figure illustrates the relative size of the channel footprints, the common off-nadir angle for all channels, and the inter-scan distance resulting from the spin rate and spacecraft ground speed. (The figure does not reflect the instantaneous projections of the beams per the feedhorn

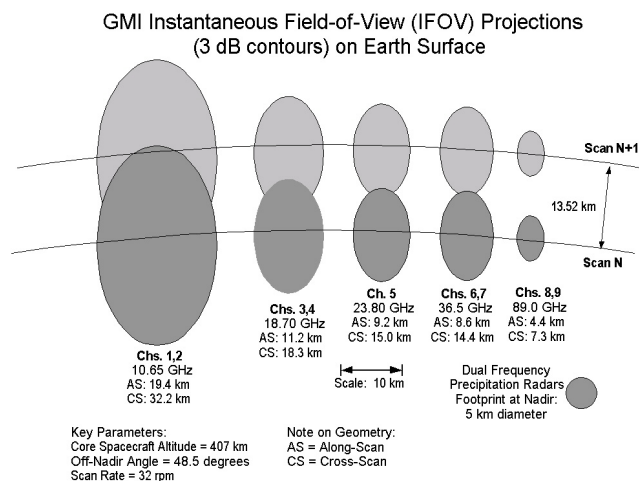


Figure 3. GMI channel footprints.

layout.) For comparison between the GMI and DPR instruments, the IFOV for the DPR radars (identical for both radars) is illustrated. For Channels 1 through 7, the IFOVs enable spatial contiguity in the cross-scan dimension. For Channels 8 and 9, the IFOVs satisfy a minimum coverage in the cross-scan dimension of 50%.

The 1.2 m diameter aperture of GMI provides excellent spatial resolution for Channels 1 through 5, the channels for which the entire aperture is utilized in beam formation. These GMI channels offer fine spatial resolution when compared to other conical-scanning radiometers. In particular, the IFOV diameters of GMI Chs. 1-5 are 50% to 60% that of the TMI IFOV diameters at the original TRMM altitude of 350 km. Likewise, for these channels, the GMI spatial resolution is comparable to that of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Conically-Scanning Microwave Imager/Sounder (CMIS) sensor, which despite its 2.2 m aperture, orbits at an altitude of 833 km.

The choice of sampling times for the GMI is governed by the desire to achieve "Nyquist" spatial sampling in the along-scan dimension of the swath. In addition, samples from individual channels must be co-registered on the Earth surface. Sample times are slightly larger than integration times due to latencies inherent to the digital sampling electronics. To satisfy the Nyquist criterion, all channels will be sampled at a minimum of two times as the GMI scans through a single IFOV. To guarantee co-registration on the Earth, sample times for each channel will be integral multiples of each other. Electronic time delays between channel sampling will account for the fixed angular differences in along-scan beam pointing due to the multiple feedhorn design. Presently, sampling times of 5.2 ms are proposed for Channels 1 and 2 and 2.6 ms for Channels 3 through 9. These values will be finalized early-on in the instrument design phase.

VII. GMI TRANSFER STANDARD, RAIN MAP ROLES

The GMI radiometer will serve as a 'transfer standard' in two contexts: (1) as a radiometric transfer standard for the other radiometers of the GPM constellation, and (2) as a

precipitation transfer standard for the retrievals of the GPM constellation. Both transfer standards represent areas of scientific research.

In the first context, that of radiometric transfer standard, the GMI radiometric calibration will serve as a reference for other radiometers. In this method, the brightness temperature calibration of constellation member radiometers will be adjusted to achieve a common basis with that of the GMI. This technique will reduce precipitation retrieval differences between sensors due to biases from inter-sensor calibration. Referencing calibration to the GMI requires that the GMI maintain excellent calibration and calibration stability through its life. In operation, the ability to create a common calibration from the GMI will depend upon statistical data from spacecraft intersection events, i.e. the viewing of common earth scenes. Such intersection comparisons are complicated by factors such as intervening clouds and precipitation, different look angles, different footprint sizes, and time delays and sample spatial separations specific to each intersection [5].

The second context refers to a precipitation transfer standard. Specifically, this concerns the measurement synergy created by the GMI and the Dual-frequency Precipitation Radars aboard the Core observatory. The mutual overlap of actively sensed, vertically-profiled, radar data at two frequencies in combination with the multi-channel passive data is a unique capability of the Core observatory. The GPM radars will be used to accurately measure, via reflectivity and estimates of attenuation, the vertical profiles of the clouds and precipitation, including the drop size distribution. This radar profiled data will be compared to the GMI radiometric retrieval and its derived profile, which are presumed less accurate than that from the radars. As part of the precipitation

transfer standard, the radar-measured profiles, and associated radiometer brightness temperatures, are included in an improved database available to the GMI as well as other GPM radiometers [6].

GPM will transfer Core observatory GMI data to the user community at very short latency. In particular, data from GMI will be continuously transferred via a Tracking and Data Relay Satellite System (TDRSS) Multiple Access (MA) link through White Sands, NM and into the availability of the user community typically 15 minutes or less from the time of measurement. A primary application for the short latency GMI data is for integration into a near-real-time global rainfall map created from measurements by all the GPM constellation radiometric sensors and with overall rain map data latency less than 3 hours.

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